Climate Change

Clockwise from the top left: Sudden Aspen Decline (SAD) in an aspen stand (U.S. Forest Service). Mountain pine beetle between Dubois and Grand Teton National Park (National Parks Traveler). Wood River near Meteetsee (WGFD). Greyrocks Reservoir during the height of the recent drought (WGFD).

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Background

Climate is a compilation of many meteorological features occurring over a long period of time. Primary elements include temperature, humidity, atmospheric pressure, air flow, and precipitation. "Weather" refers to short-term variation in these elements (i.e., two weeks or less), while "climate" refers to these dynamics over months, years, decades, centuries, and longer (NOAA 2008). Climate is controlled by many factors. It is influenced by Earth's orbit and tilt, which determine interannual changes such as the seasons. Latitude, elevation, terrain, ground cover, and presence or absence of water bodies also impact climate. These factors may affect atmospheric composition, temperature, precipitation patterns, and the many other elements mentioned previously. Climate is also affected by variables such as dust, aerosols, solar output and absorption, and concentrations of greenhouse gases in the atmosphere, namely water vapor, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

Paleoclimatology, the study of ancient climates using proxy climate records (e.g., tree rings, ice cores, sediment cores), demonstrates that climate varies naturally over long periods of time. Climate is subject to natural variability from decade to decade primarily as a result of cyclical phenomena such as El Niño-Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and North Atlantic Oscillation (NAO), which highlights the importance of long-term data when considering anthropogenic, or human-influenced, impacts to the climate system (Wiens and Bachelet 2009). The study of climate in the 20th century adds to scientific data pertaining to climate dating back thousands of years, painting a historical picture that shows both the warming and cooling of Earth's surface temperatures, as well as various drought and pluvial periods. Simply stated, historical records indicate that Earth's climate is variable and changes over time. Any scientifically recognizable, long-term variability in the aforementioned climatic elements (e.g., temperature, precipitation) is described as "climate change."

The Intergovernmental Panel on Climate Change (IPCC) was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988 as the leading body for the review and assessment of worldwide scientific, technical, and socio-economic information on climate change. This scientific body *does not* perform research or monitor the earth's climate. The IPCC is charged with reviewing voluntary scientific contributions in the field of climate change and translating and conveying to the public the presently documented and potential future consequences of this global phenomenon.

Scope and Challenges of Climate Change and Wildlife Conservation and Management

Global to Local

While climate change is a global phenomenon with broad-scale ramifications at the global level, the ecological impacts are more readily observed, experienced, and addressed at the local level. The western United States has a more diverse landscape with climate variations that are difficult to model on a fine scale, areas that are remote and inaccessible for climate research and monitoring, and a patchwork of publicly and privately owned land that influences management strategies and policy making (Joyce et al. 2007). Wyoming is a unique mixture of mountain and plains landscapes, causing the state's climate to be varied from east to west and north to south. Wyoming is also faced with several unique challenges relating both directly and indirectly to climate and climate change.

According to paleoclimatic records dating back thousands of years, drought—a period of unusually low precipitation—is a defining feature of Wyoming's climate (Gray and Andersen 2009). Examination of western climates over centuries, which is established primarily by lake sediments, tree ring cores, and packrat middens (McWethy et al. 2010), demonstrates that severe drought is a natural part of Wyoming's climate (Gray and Andersen 2009). However, the baseline for state climate is established using records of climate variability throughout the past century (Gray and Andersen 2009). Most importantly, climate records over the past 30 years are most often used to establish resource management practices. A longer historical record indicates that the 20th century was an unusually wet time period in Wyoming relative to the past several millennia (Gray and Andersen 2009).

In addition to frequent drought, Wyoming is also challenged by the regional semi-arid climate. In other words, even in non-drought periods Wyoming is a rather dry area. Wyoming is the fifth driest state in the U.S.—over 70% of the state receives less than 16 inches of precipitation annually (Gray and Andersen 2009, Water Resources Data System undated). The state also relies almost exclusively on mountain snowpack as its major water source, with 70–80% of precipitation arriving as snow (Hays 2008). A majority of the snowpack is concentrated in a relatively small area (Gray and Andersen 2009), namely the higher elevations in the northwestern and southeastern mountain ranges. Ninety percent of Wyoming's runoff is snowmelt from these areas (Hays 2008). Wyoming is clearly a headwaters state, as its mountains form the headwaters of many major rivers, including the Snake-Columbia, Green-Colorado, Yellowstone-Missouri, and Platte systems (Gray and Andersen 2009). Consequently, water that originates within the state's political boundaries is allocated to downstream states, which means that Wyoming has important water-management responsibilities and also that water availability in this state has the potential to significantly impact other states.

Warming has shifted the periodicity and intensity of snowfall and subsequent runoff in much of North America (Mote et al. 2005, Regonda et al. 2005, Stewart et al. 2005, Wilcox 2010). April 1st snowpack in western watersheds has decreased between the middle of the 20th century and the end of the century (Joyce et al. 2007). The hydrological impacts of potential warmer surface temperatures and subsequently changing snow regimes in areas of high elevation are vast and may have countless secondary implications over time. Snowpack melt will occur earlier and, consequently spring runoff will come earlier and occur faster (Backlund et al. 2008, Wilcox 2010, Gray and Andersen 2009). As a result, late-season water flows will decrease (Joyce et al. 2007), which could exacerbate drought stress and contribute to increasing water temperatures (Wilcox 2010, The National Academies 2009). Overall warmer temperatures will likely lead to increased water loss due to evaporation and plant water use and decreased water yield to lakes, streams, and wetlands (Hoerling and Eischeid 2007).

Warmer winter temperatures might also cause seasonal precipitation to fall as rain instead of snow, subsequently decreasing annual snowpack and inhibiting the recharge of ground water reservoirs (Field et al. 2007). In the western mountain region of North America, the amount of annual precipitation in the form of rain that would normally fall as snow has been significantly increasing since the middle of the 20th century (Knowles et al. 2006), and spring and summer snow cover has been decreasing (Groisman et al. 2004). The West will become more vulnerable to shifts from snow to rain if winter temperatures continue to increase (Joyce et al. 2007). Warmer surface temperatures also will likely intensify drought events, much like those on historical record (Gray and Andersen 2009). Even a small increase in average temperatures with no decrease in annual precipitation would greatly impact Wyoming's water resources (Gray and Andersen 2009). The increase in water evaporation resulting from warmer temperatures would likely offset any increase in total precipitation (Joyce et al. 2000); it would also exacerbate the drought effects of decreasing amounts of total precipitation (Stonefelt et al. 2000, Pulwarty et al. 2005). In other words, conditions that currently define drought could become more of the norm in a future climate for Wyoming (Hoerling and Eischeid 2007, Seager et al. 2007).

The Rocky Mountain West is the fastest growing region in the U.S. (Gray and Andersen 2009) (see Wyoming Leading Wildlife Conservation Challenges – Rural Subdivision). Rapidly expanding urban populations pose another challenge for Wyoming as the state must share water with diverse and growing user groups, many of whom are located in downstream, out-of-state areas (Gray and Andersen 2009). The strain placed on already limited water resources by population growth and economic development could increase regional vulnerability to extended periods of drought as a result of allocating water beyond what is annually available (Pulwarty et al. 2005).

Water and drought are a challenge for Wyoming regardless of climate change. Future projections for the western U.S. depict an increasingly warm and consequently drier climate that would alter regional and local hydrology and further strain limited water resources. Wyoming's resource managers, who are already familiar with drought planning and allocating scarce water resources for multiple uses and users, will continue to deal with these challenges in perpetuity. Good water management and planning are strong policies for the state of Wyoming under any realistic climatic scenario, and current projections of a drier climate emphasize this point.

Potential Impacts of Climate Change on Terrestrial and Aquatic Species

Species have evolved according to certain regional and local climate norms and much of their individual phenology and range is directly influenced by climate (Walther et al. 2002, Parmesan and Yohe 2003, Root et al. 2003, Parmesan and Galbraith 2004). Species respond to environmental change based on habitat needs, competitive ability, and physiological tolerances (Manley 2008). Climate change has the potential to alter species' fundamental interactions with other species, organisms, and the physical environment, which could lead to a cascade of impacts throughout the entire ecosystem (The National Academies 2009). The effects of climate change will impact both Species of Greatest Conservation Need (SGCN) and species that are not classified in this category (non-SGCN), including many invertebrates, plants, fungi, and microbes that are typically not directly addressed by state agencies.

Phenology[1]

Many species operate on seasonal cues that are directly related to climate and so changes in climate may lead to shifts in the phenologic trends of some species, impacting breeding and migration patterns and the timing of germination or flowering of plants (Parmesan 2006, Root et al. 2003). The onset of spring, as measured by the timing of a variety of natural phenomena, has been occurring earlier since the 1960s (Walther et al. 2002), which in turn has been impacting some species' observable climate-sensitive behaviors such as breeding, hibernation, migration, productivity, and range (Joyce et al. 2007). Species movement patterns may change according to the duration of the seasons, food availability, and altered migratory routes (Backlund et al. 2008). Migratory species may begin arriving at seasonal and transitional feeding grounds earlier and leaving later in reaction to climate change, or continue arriving and leaving on time even though climate has altered the seasonal processes of stop-over and breeding grounds (Visser and Both 2005).

Not all species are expected to alter their behavior in response to changing climate factors in the same way or at the same rate (Visser and Both 2005, Visser et al. 2004), and there is no guarantee that species responses will be synchronized to the responses of their forage resources. Such mistiming could have significant impacts on the structure of the ecosystem and the relationships of the species within that system. Changing species relationships will have a more significant impact

[1] Phenology is the study of plant and animal life-cycle events that are influenced by variations in climate on an annual or interannual timescale. See Cayan et al. 2001 and Inouye et al. 2000 in the Literature Cited section for specific examples of studies that have documented phenologic changes in species in the western U.S.

on ecosystem structure and function than changes to any one particular species (Harrington et al. 1999, Visser and Both 2005).

Abundance and Biodiversity

The mistiming of specific species' behaviors and forage resources to climate change and subsequent impacts to species relationships such as competition and pollination could result in complex changes to population sizes and densities. For instance, population size may decline if breeding is mistimed with a seasonal food source that peaks at a different time than historically observed, but may increase if forage is available earlier and lasts longer. More directly, populations and species may be affected by changing climate extremes. Changes in species abundance can lead to shifts in community make-up, changing interactions among species and the environment, and the emergence of new, novel communities and species interactions (Walther et al. 2002). Overall biodiversity may be altered by changing climate conditions as some species manage to adapt, some species move, and some become extirpated or extinct.

Genetic Diversity and Morphology

Climate change may also impact genetic diversity and species' morphology (Root et al. 2003). Genetic diversity fluctuates with population size and connectivity, and for many species the transition to a warmer and drier environment will translate to a rapid fragmentation of suitable habitat. Habitat fragmentation and landscapes that are increasingly being altered by human activities severely hinder species mobility and dispersal capacity (Pitelka and The Plant Migration Working Group 1997). Furthermore, warmer and drier conditions may select for individuals with smaller body sizes or other morphological adaptations, eventually resulting in populations with substantially different physical or physiological characteristics than today (Koopman 2008, Root et al. 2003).

Range

Not all species have the same level of plasticity in the face of environmental change, and many may not evolve quickly enough to adapt to changing climate conditions in situ (Parmesan 2006). Some species may shift their range in order to track the physical and biological conditions to which they are already adapted (Root et al. 2003). Climate change may cause species' ranges to expand, contract, or fragment (Ruggiero et al. 2008, Koopman 2008). Warming temperatures are expected to result in a general movement of species' ranges up in both elevation and latitude as a result of physiological tolerances and/or specific habitat needs. Populations of species currently persisting only at high elevations may fragment, forming small isolated populations on mountaintop islands. For example, some low-elevation pika (Ochotona princeps) populations that have been studied in the Great Basin have reportedly gone extinct since the 1930s, while populations inhabiting higher elevations remain intact (Beever et al. 2003, Parmesan and Galbraith 2004).

Similarly, warming water temperatures may drive cold- and cool-water fish species to new ranges or lead to local extirpation or extinction, while high-elevation fisheries may become more productive as temperatures warm. Ranges of cold-water species may contract, while species that are tolerant of warmer water temperatures may continue to expand their range (Stefan et al. 2001). The range of some plant species may also be affected by climate change, and vegetation redistributions may occur as a result of climate factors such as temperature tolerances, water limitations, pollinator interactions, and seed dispersal ability.

Both native terrestrial and aquatic species may increasingly be impacted by nonnative species that cross political boundaries in an effort to disperse and capitalize on opportunities for range expansion resulting from the decline of native species (Walther et al. 2002). Invasive species may contribute to the loss of biodiversity, changes in the abundance and distribution of native species, and alteration of species community structure, and may even cause local population extinctions (Joyce et al. 2000) (see Wyoming Leading Wildlife

Conservation Challenges – Invasive Species). Some species will be successful in fulfilling habitat needs in more favorable climate and some, which are less mobile or adaptable, will not (Midgley et al. 2002).

Species with specific trophic relationships likely will not respond to climate changes in the same way or at the same rate, which may lead to local extirpations, extinctions, community breakdown, and structural reorganization (Root and Schneider 2002, Schmitz et al. 2003). Research indicates that species have responded to rapid climate change in the past, and some have already begun responding to the warming and other changing climate conditions that have occurred in the 20th century. Natural resource managers need to begin considering how both the direct and indirect effects of climate change may unfold across the landscape (Joyce et al. 2007). However, resource managers must also take into consideration a variety of non-climate drivers that impact species distribution (McWethy et al. 2010).

Other Stressors

Many of the potential effects of climate change on wildlife may occur as a result of the exacerbation of other challenges and stressors that affect species irrespective of climatic conditions. Other stressors include habitat fragmentation, loss, and disturbance; limited and declining quality of water resources; invasive species and disease; and declining species populations; among other things.

In particular, warmer surface temperatures could alter the survival and reproduction rates of some pathogens and vectors, which may currently be constrained by temperature minimums and maximums, potentially affecting the virulence and incidence of wildlife diseases like brucellosis, chronic wasting disease, whirling disease, West Nile virus, and bluetongue disease, as well as important plant pathogens such as white pine blister rust and mountain pine beetle.

Although all species will be affected by changing climate conditions, not all species will experience the same effects—some will benefit, while others will struggle. The species that may be at highest risk for dramatic impacts from climate change are those with limited ability to adapt. Species that are endemic to a particular area may be at greater risk than those that are geographically widespread. Similarly, species with an ability to move and adjust their range with changing conditions may have more success adapting than those that are unable to disperse or are relatively sedentary. Boreo-alpine taxa, which are already restricted to high elevations, will have limited options for population migration/dispersal as the climate warms and becomes more arid. Species that are habitat specialists or rely on specific interactions with other species, organisms, or physical aspects of the environment may be at greater risk of adverse effects of climate change than species that are more generalist in nature. Additionally, climate change has the potential to negatively impact species with low physiological tolerances to changing atmospheric, local weather, or environmental quality conditions. Finally, populations of species that have low genetic diversity or that have experienced recent or ongoing declines in population size may be more vulnerable to the effects of climate change than those species that have populations that are both rich and abundant (Midgley et al. 2002).

Potential Impacts of Climate Change on Habitat

Species survival depends largely on sufficient and healthy habitat; intact critical areas, such as breeding grounds or spawning beds; and connectivity among these areas (Joyce et al. 2000). Here again, non-climate stressors and natural ecological occurrences that are exacerbated by climate change may have the biggest impacts on habitat quantity and quality.

Terrestrial Habitat

The 11 terrestrial habitat types that are described in this SWAP include various types of forested land, shrublands, and grasslands; riparian areas and wetlands; and rocky areas with little vegetation (see Wyoming Habitat Descriptions – Terrestrial Habitat types).

Wyoming's diverse terrestrial habitats are home to SGCN and non-SGCN alike, and all are influenced by regional climate and will be affected in some way by changing climate conditions. The structural components of an ecosystem may be significantly altered by changing interactions among species, which can impact the quality and quantity of habitat. Natural landscape disturbances, which may be compounded by changing climate factors, will likely have profound effects on Wyoming's terrestrial habitat.

Wildfire is increasingly causing stress to mid-elevation forests as both the length of the fire season and the average area burned each year increases in the U.S. The length of the fire season has increased 78 days over the past 3 decades (Westerling et al. 2006), and is expected to grow by an additional 2–3 weeks by 2070 (Barnett et al. 2004). Over the past 20 years, the average area burned in the West has increased six-fold (Westerling et al. 2006). Climate is one factor among many that may influence the frequency and severity of wildfire (see Wyoming Leading Wildlife Conservation Challenges – Disruption of Historic Disturbance Regimes). Wildfire is a natural occurrence that regularly alters vast expanses of wildlife habitat. Coupled with the effects of climate change—namely warming temperatures, drought, and vegetation changes—wildfire may lead to more major ecosystem changes in the future. Water limitations resulting from the increased intensity of regional drought could hinder forest regeneration, causing meadow and grassland ecosystems to permanently replace current woodlands and forest (Joyce et al. 2007). Frequent fire also discourages the recovery of shrublands, and thus some of Wyoming's sagebrush habitat could be permanently converted to grassland (Bureau of Land Management undated).

Forests are natural water filters and flow regulators. The general loss of forested land predicted under a warmer and drier climate may compound water-quality issues and irregular hydrological flows, which are also being impacted more directly by rising surface temperatures. Overall declines in vegetative cover as a result of increased intensity and severity of wildfire may lead to further habitat alteration by damaging organic soils and causing increased soil erosion (Spigel and Robichaud 2007). Erosion can lead to increased runoff, sedimentation, and debris flow in streams and rivers, which can negatively impact aquatic habitat and associated species (Rieman and Clayton 1997, Dunham et al. 2003).
Periodic outbreaks of insects as a result of favorable climate or ecological conditions are a natural occurrence that may also be exacerbated by climate change. Perhaps the most widespread example of insect proliferation and outbreak is the ongoing pine bark beetle epidemic that is affecting vast tracts of forest throughout western North America (see Wyoming Habitat Descriptions – Montane and Subalpine Forests). Bark beetle outbreaks are a natural part of forest ecology; however, researchers suggest that warmer winters in recent decades coupled with drought have caused forests to become more susceptible to the prolonged and more intense epidemic that is currently occurring (Hicke et al. 2006, Romme et al. 2006). Warmer temperatures may be allowing for enhanced beetle population growth and range expansion to higher-elevation forests (Joyce et al. 2007). Large, contiguous tracts of dead and fallen trees as a result of beetle kill also create a greater risk for vast and frequent wildfire, as well as impacts on local and regional hydrology including changes in annual water yields, peak flows, and low flows. Research also suggests that the loss of large numbers of trees in concentrated areas impacts local weather and atmospheric conditions by causing changes in precipitation, temperature, and air quality, which may further impact wildlife by leading to more vegetative restructuring (ScienceDaily 2008). Wildlife managers may also encounter difficulty with maintaining hunter access to public lands resulting from increasingly hazardous forest conditions.

Climate change has the potential to intensify periodic drought. Prolonged and more severe drought will significantly alter terrestrial habitat, affecting a range of species that rely on these habitats and associated resources. The combination of drought and increased evaporation from surface water and terrestrial ecosystems as a result of warming surface temperatures may have severe effects on wetlands and riparian areas. These areas could become increasingly sparse and/or less connected, or may dry up completely. Wetlands and riparian habitat are vitally important to aquatic and terrestrial species in Wyoming, providing both shelter and forage. A vast majority of species use these areas either daily or seasonally as part of their lifecycle, and many of Wyoming's bird species are wetland or riparian obligates (Nicholoff et al. 2003, Copeland et al. 2010). These habitats also serve as migration and dispersal corridors. The alteration of wetlands and riparian areas may also compound other hydrological effects of climate change by contributing to a decrease in surface water storage, less flood control, decreased filtration of sedimentation, and uncontrolled stream flow (Copeland et al. 2010), all of which impact the quality of species' habitat.

Long periods of drought may cause a decline in forested area as the land becomes too arid to support forest ecosystems (Joyce et al. 2007, The National Academies 2009), and may further increase the susceptibility of forests to insect epidemics (Logan et al. 2003). Decreasing soil moisture could also kill trees planted for shelterbelts and cottonwood galleries, both of which provide important habitat for numerous terrestrial species. Finally, drought may cause terrestrial habitat such as shrublands, sagebrush, and perennial grasses and forbs to decline due to water limitations (Bureau of Land Management undated). Such habitats may convert to other types or may simply become more barren of vegetation, consequently decreasing the forage value of the land, increasing susceptibility to the invasion of drought-tolerant species and wildfire, and leading to the decline of associated wildlife species.

As ecosystems and landscapes are altered by changing climate conditions and other disturbances, the opportunity for exotic and invasive species to establish populations in Wyoming may increase. Terrestrial habitat may be increasingly affected by invasive flora that can outcompete native flora in a warmer climate and in a landscape that is more frequently being disturbed by wildfire, insect outbreaks, and drought (Bureau of Land Management undated). Increasing amounts of valuable and structurally diverse habitat may be altered by invasive plant species, which in some cases may result in a naturally diverse mosaic of native communities being converted into a more monotypic habitat (see Wyoming Leading Wildlife Conservation Challenges – Invasive Species).

The viability of riparian areas, which are highly productive and provide critical habitat for species (see Wyoming Habitat Descriptions – Riparian Areas), is also being affected by invasive species such as Russian olive and tamarisk (Bureau of Land Management undated, Archer and Predick 2008, Wilcox 2010), and the impacts of these invasive species may be exacerbated by the effects of climate change (see Wyoming Leading Wildlife Conservation Challenges – Invasive Species). As changing climate conditions alter average seasonal temperatures and the hydrology of the West, riparian areas may become increasingly important as corridors for species movement to more suitable habitat, refuge, and also important areas for terrestrial grazers (Western Governors' Association 2008).

Aquatic Habitat

The State Wildlife Action Plan (SWAP) identifies six aquatic basins in Wyoming (see Wyoming Habitat Descriptions – Aquatic Basin types). The potential impacts of climate change on water resources in Wyoming may significantly affect aquatic habitats and, like terrestrial habitats, exacerbate existing stressors to these ecosystems and the species they support.

Climate change may significantly impact hydrology in terms of both water quality and quantity, which could have far reaching impacts on aquatic habitat and the species that rely on that habitat. Warmer water temperatures resulting from increasing average surface temperatures decrease the oxygen saturation of the water and may negatively affect the viability of the habitat for some native aquatic species (Ficke et al. 2007, Western Governors' Association 2008). Increased air temperature, combined with changing atmospheric composition may also change water chemistry and the primary productivity of aquatic habitat (e.g., algal blooms).

Climate change has been causing mountain snowpack to melt earlier and run off faster in recent decades. Coupled with more severe storms in the future, this could cause more incidents of flooding (Backlund et al. 2008), especially when the previously discussed landscape changes are taken into consideration. Flooding has the potential to alter water quality by modifying aquatic root systems that filter sediments (Manci and Schneller-McDonald 1989), alter geomorphic features of streams and rivers, change riffle and pool distributions, and scour spawning beds (Joyce et al. 2007, Western Governors Association 2008). Decreasing late-season water flows resulting from early runoff and increased evaporation may cause the disappearance of isolated pools, contribute to warming water temperatures, and further lead to aquatic habitat fragmentation and fish mortality (Rahel et al. 1996, Field et al. 2007).

Wyoming's waters are already home to many nonnative species (e.g., walleye), some of which are deliberately promoted by managers, and waters are also threatened by the invasion of undesired species that are afflicting neighboring states (e.g., zebra and quagga mussels) (see Wyoming Wildlife Conservation Challenges – Invasive Species). As aquatic habitat continues to be altered by climate change and non-climate stressors, rivers, streams, lakes, and other bodies of water may become increasingly susceptible to invasive flora and fauna that are more tolerant of and/or adaptable to changes in water quality and quantity.

Climate Change and Uncertainty Regarding Impacts on Species and Species Interactions

The potential impacts of climate change on fish and wildlife and alterations to habitat in Wyoming are uncertain. While a high probability for change exists, the changes may play out in a variety of ways that, at times, will be unpredictable. Examining the ecological and biological impacts of long-term changing climate conditions may be confounded by the natural short-term and interdecadal cycles of changing trophic relationships (Schmitz et al. 2003). Peaks in the populations of some species and declines in others are often a natural part of the ecological narrative in relationships among species. Determining which changes are related to long-term climate trends may prove difficult depending on monitoring protocols and the availability of long-term data.

Modeling can be a useful tool to evaluate regional climate changes and to determine potential future critical habitat locations and species distributions that may result from climate changes. Regional climate modeling may help resource managers identify ecosystems at risk of transformative change. Bioclimatic models, also called envelope models or ecological niche models, may be used for predicting the future range and distribution of native and invasive species (Jeschke and Strayer 2008). Resource managers may be able to use these models to help target management strategies on focal areas where plant or animal species are most likely to survive in the future given climate constraints on the landscape (Bradley 2010). However, these models may also oversimplify estimates of suitable range and habitat by not accounting for non-climate drivers of species distribution, and so while these models may help paint a broad picture of future conditions, management actions should not be based solely on one model and should consider or address change at the appropriate level (e.g., regional or basin level, as opposed to sub-basin level).

Current Initiatives to Understand the Implications of Climate Change[2]

Strategies developed by government agencies and conservation organization to address climate change range from international monitoring and modeling efforts, to federal legislation, to efforts of national and regional conservation organizations, to state and local working groups holding public forums for discussion and completion of on-the-ground projects. The initiatives that follow do not constitute an all-inclusive list of climate change initiatives relevant to Wyoming, but are meant to paint a picture of the various agencies, organizations, and institutions that are providing leadership in the field of climate change science, mitigation, and adaptation.

International

The North American Regional Climate Change Assessment Program (NARCCAP) (http://www.narccap.ucar.edu/) is an international partnership using regional climate models (RCMs), atmosphere-ocean general circulation models (AOGCMs), and special report emissions scenarios (SRES) to generate future climate change scenarios for the purpose of analysis, impact studies, or further downscaling. The climate scenarios that are generated model historical climate trends (1971–2000) and project future climate trends (2041–2070) for the conterminous U.S., northern Mexico, and most of Canada. NARCCAP evaluates and estimates the uncertainty associated with the regional-scale climate change scenarios and aims to produce high-resolution (50 kilometers) climate change scenarios, which will aid resource managers in performing impact assessments on the resources that they are charged with protecting.

NatureServe (http://www.natureserve.org/) is a nonprofit conservation organization established in 1994 with guidance and resources from The Nature Conservancy. The organization is an association of natural heritage programs in the U.S., Canada, Latin America, and the Caribbean. These programs are widely drawn on by resource managers because they are the best source of information on rare and endangered species and sensitive ecosystems. The goal of NatureServe is to provide a clearinghouse for information on biodiversity that is easily accessible to resource managers and policymakers. NatureServe is responsible for the development of the Climate Change Vulnerability Index (CCVI), which is a tool that can be used to rank the level of vulnerability of individual species to climate change. The Wyoming Natural Diversity Database (WYNDD) is the state's natural heritage program, which is located at the University of Wyoming.

National

At the federal level, the U.S. Fish and Wildlife Service (USFWS) is at the forefront of developing strategies and evaluating the potential impacts of climate change on wildlife and habitat. In 2009, the USFWS released a revised draft of its strategic plan for responding to climate change (U.S. Fish and Wildlife Service 2009). The strategy emphasizes the need to move forward with decisive conservation action to address climate impacts despite the uncertainty that surrounds climate change in the future. The document is focused on three main strategies: adaptation, mitigation, and engaging partners. The USFWS also emphasizes landscape-scale approaches as part of the agency's National Fish and Wildlife Climate Adaptation Strategy (http://www.fws.gov/home/climatechange/). Twenty-one Landscape Conservation Cooperatives (LCCs) have formed that encompass all regions of the U.S. and some areas in Canada and Mexico. The purpose of the LCCs is to coordinate regional science and resources to address climate change and provide conservation delivery. Wyoming is divided unevenly by five LCCs, but the majority of the state's land area is covered by two cooperatives,

[2] The majority of the information in this section was obtained from the specific website of each initiative, unless otherwise noted.

the Plains and Prairie Potholes LCC and the Great Northern LCC.

The Department of the Interior (DOI) and the U.S. Fish and Wildlife Service administer funding to states to support the State Wildlife Grant program. States are strongly urged to use some of the funding to address climate change as part of their State Wildlife Action Plan (SWAP) and for projects that are aimed at mitigating the effects of climate change or that aid wildlife populations in adapting to changes.

The U.S. Geological Survey (USGS) established the National Climate Change and Wildlife Science Center (NCCWSC) (http://nccwsc.usgs.gov/) in response to the climate change science gaps that exist that may prohibit the development of sound management strategies for wildlife adaptation. Working with various partners at all levels, including eight regional Climate Science Centers (CSCs) established by the Department of the Interior, the NCCWSC will focus on using scientific data and modeling to make predictions about future species response to climate change and habitat and ecosystem changes that may occur. The CSCs will work in coordination with the Landscape Conservation Cooperatives (LCCs) to gather information and make resources and management tools accessible to resource managers. The USGS also supports research that explores ecosystem responses to climate change, including a project called Exploring Future Flora, Environments, and Climate through Simulations (EFFECTS).

In 1990, the U.S. Congress passed the Global Change Research Act (P.L. 101-606), which established the U.S. Global Change Research Program (USGCRP) (http://www.globalchange.gov/). The USGCRP is comprised of 13 federal departments and agencies and is charged with leading the nation in understanding global changes (e.g., climate, ozone, land cover) and making assessments and predictions to aid decision-making regarding the potential outcomes of these global changes. The USGCRP produces an annual report for Congress, *Our Changing Planet*, documenting its findings and recommending response actions.

The National Wildlife Federation (http://www.nwf.org/) and the National Fish Habitat Action Plan (http://fishhabitat.org/) are examples of wildlife conservation organizations and protection and restoration initiatives that are addressing the issue of climate change through research, mitigation, partnerships, and public education efforts. See Additional Resources within this section for more information on these organizations and relevant publications.

Regional

The Northern Rocky Mountain Science Center (NOROCK) (http://www.nrmsc.usgs.gov/) has stations located in western Montana and Wyoming. The goal of NOROCK scientists and staff is to research and disseminate information specific to species and ecosystems in the northern Rocky Mountain region to aid federal, state, and local resource managers in developing effective management strategies. One of the center's projects focuses on climate change in mountain ecosystems, including research on glaciers, snow and avalanches, and the structure and function of mountain ecosystems.

The Western Governors' Association (WGA) (http://www.westgov.org/) is a coalition of governors from 19 states and 3 U.S.-flag Pacific islands. The WGA focuses on issues that challenge western resources and economies. In addition to a policy resolution on climate change mitigation measures, the WGA has adopted a policy resolution that supports research into adaption measures. The association has developed a number of initiatives and internal working groups to address natural resource issues facing the West including water, forest and rangeland health, wildlife corridors, renewable energy, carbon sequestration, and alternative transportation fuels.

The Wildlife Conservation Society (http://www.wcs.org/), World Wildlife Fund (http://www.worldwildlife.org/), and the Greater Yellowstone Coalition (http://www.greateryellowstone.org/) are organizations that have regional initiatives that are working to research and understand the impacts of climate change on wildlife, resources, and land management. See Additional Resources within this section for more information on these organizations and relevant publications.

State and Local

The Climate Issues Committee originated as the Governor's Drought Task Force in response to the drought conditions that were impacting Wyoming in 2000. The task force was dissolved and reformed as the Climate Issues Committee in 2008 and set to address broader climate-related issues that impact the state. The committee meets twice a year as appropriate, around April/May to assess the summer outlook and in November/December to recap what happened throughout the year. It is led jointly by the director of the Wyoming Department of Agriculture and the State Forester, and committee members include representatives from several state and federal agencies throughout Wyoming, representatives from the University of Wyoming, and also from the Wyoming Business Council and conservation districts.

In 2009, Governor Freudenthal signed legislation that created a legal framework for ownership and regulation of geologic carbon dioxide (CO2) storage in Wyoming. While the Wyoming Legislature has established that subsurface pore space is owned by the owner of the surface rights, under this legislation the liability and ownership of the stored CO2 belongs to the industry that injected it into the ground. Mineral rights supersede carbon sequestration rights. The pore space rights of multiple landowners are unitized or aggregated for the purpose of carbon sequestration projects, but only if at least 80% of the landowners are in agreement (Pew Center on Global Climate Change undated). The Wyoming Department of Environmental Quality is charged with long-term oversight of underground CO2 storage. This legislation facilitates the continued research and initiation of carbon sequestration projects in Wyoming, which could be a major aspect of future climate change mitigation efforts.

The Wyoming Landscape Conservation Initiative (WLCI) (http://www.wlci.gov/) is a collaborative, landscape-scale effort to conduct research to assess the state of wildlife habitat in southwest Wyoming and complete on-the-ground projects to work to improve habitat and to safeguard wildlife, including 5 species of big game and 151 non-game SGCN. The Green River Basin area is threatened by both energy and residential development, and the area supports not only wildlife and wildlife-migration corridors, but also domestic livestock and family livelihoods. The WLCI funded nearly 40 projects from 2007–2009, and nearly 20 new projects have been proposed for 2010. Projects focus on restoring biological and age-class diversity to terrestrial and aquatic habitats; vegetation monitoring and modeling, including projects to control invasive species; protecting migration corridors and restoring habitat connectivity; and working with landowners to create conservation easement agreements. The WLCI is also supporting projects that evaluate the potential effects of climate change on wildlife and habitat in the region. The majority of the initiative's funding comes from its permanent federal agency partners.

The University of Wyoming houses and supports many different research organizations whose research may directly or indirectly involve climate and the impacts of climate change. The Wyoming Cooperative Fish and Wildlife Research Unit (http://www.uwyo.edu/wycoopunit/) is a partnership between the U.S. Geological Survey, U.S. Fish and Wildlife Service, University of Wyoming, Wyoming Game and Fish Department, and the Wildlife Management Institute. The research unit is located at the University of Wyoming in the Zoology and Physiology Department. Recently, the research unit has started to examine the past effects and potential future impacts of climate change on ungulates in the Rocky Mountain region.

The Water Resources Data System (WRDS) (http://www.wrds.uwyo.edu/) and the Wyoming State Climate Office (SCO) (http://www.wrds.uwyo.edu/sco/climate_office.html) provide Wyoming citizens, managers, and policymakers with comprehensive hydrological and climatological data from throughout the state. The offices are funded by the Wyoming Water Development Office and are located at the University of Wyoming. The WRDS and SCO compile information on hydrologic and climatic conditions from various resource managers and monitoring sources such as the Bureau of Reclamation and the National Weather Service, and develop the information into usable formats such as maps that depict climate trends over multiple decades. The offices are Wyoming's leading sources on drought information for the state, and the data products they develop help resource managers to identify climate trends and extremes.

Current Challenges for Effectively Managing Climate Change

Climate Change Certainties and Uncertainties

The study of climate over the past century has provided scientists with information about recent climate trends resulting from a combination of natural forces and anthropogenic influences. Studies indicate that Earth's surface temperatures gradually increase and decline over periods of time spanning hundreds of years as a result of solar activity, volcano eruptions, sea surface temperature, and pressure anomalies (McWethy et al. 2010). An examination of temperature records over the past two centuries demonstrates that surface temperatures generally have been increasing worldwide (Intergovernmental Panel on Climate Change 2007). Many uncertainties also exist with regard to the science of modeling and projecting future climate variability and associated ecosystem outcomes. However, uncertainty does not necessarily mean that historical observations and future projections are wrong or inaccurate, but they maybe qualified as inexact due to many uncontrollable variables.

The general scientific consensus on temperature change is that average global temperatures will continue to increase, as will temperatures in North America and the Rocky Mountain West, including Wyoming (Christensen et al. 2007). Temperature records over the past 100 years indicate that the West is already experiencing warming trends, particularly in winter and spring (Joyce et al. 2007). Recent research efforts have put forth a range of projections regarding temperature increases over various spatial (e.g., global, regional, national, statewide) and temporal (e.g., mid-century, late-century) scales, but the rate and magnitude of changes may depend on a suite of factors including global economic growth, adoption of climate change mitigation measures, and interactions between natural variability and the consequences of changing greenhouse gas concentrations.

Consensus on precipitation is more elusive than consensus on temperature. The IPCC projects that overall global precipitation will increase as a result of warmer ocean temperatures (Christensen et al. 2007). However, precipitation is not expected to increase everywhere: currently wet regions are expected to get wetter and dry areas drier. The western United States, including Wyoming, is likely to become drier (Backlund et al. 2008). The past 100 years of precipitation records do not demonstrate any definitive precipitation trends in the West but do indicate a high level of variability (Joyce et al. 2007). Additionally, certain climatic events are expected to intensify. Storms may become more severe with more precipitation in a shorter amount of time, and droughts may extend over longer periods of time much like the megadroughts identified in the historical record (Gray and Andersen 2009).

Climate and Ecosystems

The fact that climate affects biological systems is well established, but how rapid or transformative climate change will impact these systems is less certain. Climate may alter the physical structure of the ecosystem, which includes living organisms (i.e., aquatic and terrestrial wildlife) and non-living, chemical, and physical environmental attributes (Westerling et al. 2006, Rosenzweig et al. 2008). Climate change may also lead to changes in core ecosystem functions such as energy exchange, nutrient cycling, and primary productivity, which form the basis of the ecosystem services (e.g., clean air and water) on which human populations depend.

Large and rapid changes have the potential to place a greater amount of stress on components of the system than long-term gradual changes, which is a concern for many species and ecosystems (Schneider and Root 1998). "Abrupt" climate change is defined as a rapid change in climate over a relatively short period of time, which causes significant disturbance to ecosystems (U.S. Climate Change Science Program undated). Currently, the rate of change is likely a greater threat to ecosystem viability than the actual amount of projected change. Ecosystem change may occur in step-like transitions involving long periods of time with minimal change, followed by a relatively rapid development when conditions are right (Jackson et al. 2009, Gray et al. 2006, Lyford et al. 2003).

Climate may directly or indirectly impact ecosystem structure and function in many ways. Climate impacts average seasonal temperatures and temperature extremes. In turn, temperatures have profound effects on hydrology, including the spatial and temporal patterns of snowpack accumulation and ablation, runoff, water storage and recharge (e.g., glaciers and aquifers), evaporation, and soil moisture (Gray and Andersen 2009, Barnett et al. 2004, Christensen et al. 2007). Climate influences the frequency and intensity of disturbances such as drought, insect and disease outbreaks, storm severity, flash flooding, erosion, and wildfire, and may promote the establishment of invasive and/or exotic species in arid landscapes (Backlund et al. 2008). It may extend or curtail the growing season and impact primary production (Backlund et al. 2008). Climate influences plant and animal migration, distribution, and interaction patterns, and also the survival and proliferation of pathogens and parasites (Backlund et al. 2008, Harvell et al. 2002).

The physical manifestations of climate change have been observed and documented throughout the 20th century and up to present day (e.g., Parmesan 2006). Scientific records show that average global surface temperatures have risen by about 1˚F (0.6˚C), global sea levels by 15–20cm, and global overland precipitation by about 2% since the beginning of the 20th century (Backlund et al. 2008). Most of the continental United States experienced increased precipitation, stream flow, stream temperatures, and glacial retreat (Backlund et al. 2008, Wilcox 2010).

The ecological manifestations of climate change have been similarly documented. Increased vegetation growth, vegetation redistribution, and changes in flora phenologic trends have been observed (Backlund et al. 2008, Cayan et al. 2001). Net primary production (NPP) increased approximately 10% from 1982–1998 (Boisvenue and Running 2006). The advance of the spring season has caused earlier blooming and onset of spring greenness; warming temperatures, which are more pronounced at high elevations and latitudes, may be contributing to the infilling of sub-alpine conifers in alpine tundra; and increasingly limited water resources may be causing drought-tolerant vegetation to shift its range (Myneni et al. 2001, Lucht et al. 2002, Joyce et al. 2007). Changes in the migration and phenologic patterns of some terrestrial species and the displacement of native high-latitude species also have been observed (Walther et al. 2002). Research on the direct and indirect impacts of climate change will likely increase in the future as changes continue to materialize or become more apparent.

Climate change may present human populations and fish and wildlife populations with various tradeoffs. Seasonal changes, such as an earlier spring and a later fall, will increase the length of the growing season resulting in increased agricultural production and extended foraging time for wildlife. However, if warmer temperatures are not coupled with increased precipitation, summer and late-season drought stress will likely adversely impact primary production. Forage quality may be negatively impacted by changing CO2 concentrations (Joyce et al. 2000), and invasive species, which may be more tolerant of changing climate conditions (Joyce et al. 2007). Warmer and milder winters may entail less wildlife winter mortality, but increasingly severe storms, changing temperature extremes, wildfires, and drought may adversely affect reproduction and the survival of young. Climate change is not inherently good or bad, but it is a shift from a previously managed state or structural organization, which will entail tradeoffs, new management goals and strategies, and winners and losers.

As long as global surface temperatures continue to increase and precipitation patterns become more variable, biological systems will be in a constant state of transition. Consequently, using a historic range of variation, formally or informally, to guide future management strategies may be insufficient and even inappropriate for facing the additional challenges that rapid climate change will bring to wildlife and habitat management (Wiens and Bachelet 2009, Joyce et al. 2007). Using 100 years or less of past climate data to inform future management strategies does not capture the variability that long-term proxy data can depict (McWethy et al. 2010) and likely will not accurately account for the ecosystem changes that will occur as a result of recent and future climate change. Goals and conservation strategies may need to be redefined in order to address the needs of wildlife in transitioning systems.

Climate Modeling

Climate change is a global phenomenon driven by large-scale dynamics that affect weather and climate conditions at the regional and local levels (Wiens and Bachelet 2009). At present, General Circulation Models (GCMs) use simplified representations of Earth's oceans, atmosphere, and land surface, and the interactions among these units to help paint a broad picture of general climate patterns and trends and to make projections regarding future possibilities. GCMs can also be run under various assumptions about future greenhouse gas emission levels to output projections about future climate across a variety of social and economic scenarios.

Unlike efforts aimed at short-term weather forecasting, the goal of most GCM-based research is to understand general patterns of climate variability and climate averages. As such, GCMs perform reasonably well in recreating both historical climates seen in instrumental observations and paleoclimates preserved in various proxy archives (e.g., tree rings). This, in turn, generates reasonable confidence in future climate projections, with the major caveat that economic and social variables that relate to greenhouse gas production are highly uncertain (Gray, personal communication, July 9, 2010). However, the usefulness of GCMs in applications related to wildlife management can be greatly limited by their course-scale output and the fact that they do not fully account for topography and ecosystem boundaries that often impact regional and local climate (Barnett et al. 2004).

Based on their ability to reproduce paleo and historical patterns, as well as the underlying chemistry and physics of climate change, scientists have much more confidence in the ability to predict future temperatures than they do for precipitation (Gray, personal communication, July 9, 2010). However, difficulty may still arise when attempting to distinguish between variations associated with climate change and variations driven by forces such as the El Niño-Southern Oscillation (Wiens and Bachelet 2009). Despite the noted uncertainties and shortcomings of climate modeling, the information produced by these models may be useful for predicting the potential vulnerability of an area to climate change, possible vegetation shifts, and future habitat suitability.

Given the uncertainty associated with global modeling, resource managers should avoid developing management strategies based on a single set of climate projections (Wiens and Bachelet 2009). Managers should instead take action by integrating a wide range of possible climate change scenarios into planning, conservation, and management efforts.

Recommended Conservation Actions

Introduction

Water management and drought are issues that Wyoming has dealt with in the recent past, as well as consistently throughout its history, and they will continue to be paramount as the climate changes, whatever direction the change may take. Although a lot of uncertainty surrounds the issue of climate change, in part because climate in the western U.S. is highly variable and spatially heterogeneous, the science, literature, and experience of resource managers generally confirms that changes are not always gradual and even small changes can have big impacts on the landscape and natural resources. Wildlife will continue to be confronted by a diversity of threats, many of which are influenced by climate and are likely to be exacerbated by rapidly changing climate conditions. While changing climate conditions may favor some highly adaptable and opportunistic species, the projections for this region, namely warmer and drier conditions, may lead to significant loss of abundance and diversity of native fish and terrestrial wildlife as habitat becomes more limited, fragmented, and affected by disturbances.

Currently, wildlife and habitat managers in Wyoming work within the bounds of existing policies and use conservation strategies to maintain healthy and diverse species populations and landscapes to support those species. The future management of individual species, communities, and ecosystems may require increasing flexibility given the uncertainty of future climate conditions and the rate at which conditions are predicted to continue to change. Dynamic and adaptive strategies developed by resource managers may more effectively manage systems in transition than strategies that aim to maintain a historical range of variation or that resist change altogether. Similarly, a proactive approach to anticipated climate variability may yield more successful results than management actions that are reactive responses to wildlife populations and habitat that already have been significantly impacted directly or indirectly by climate change.

Regional climate variables have long been factored into the management of aquatic and terrestrial wildlife populations and habitats. Understanding historic climate variability may help resource managers identify current climate-related changes and develop an idea of how individual species and communities may respond to future changes (McWethy et al. 2010). Incorporating considerations of climate change into WGFD planning does not alter the basic mission of the department or its core principles, nor does it require department wildlife and habitat managers to quantify climate change throughout Wyoming. Climate change consideration may simply require deliberate assessment of the role of climate in current activities and evaluation, and perhaps eventual re-prioritization, of the primary causes of wildlife population decline and fragmentation of Wyoming's native species and how best to maintain or restore healthy wildlife populations and landscapes. Although uncertainty remains with regard to future climate projections, just as there is uncertainty with any management-relevant variable, a growing scientific consensus suggests that the effects of heightened aridity, warmer temperatures, and overall more variable conditions should be considered by the WGFD, as these climate factors are important drivers of future wildlife populations in Wyoming. Additional resources will be necessary to fully implement the recommendations and monitoring activities that follow, and they should be carried out or completed as resources allow.

Goals and Strategies

In light of the uncertainty regarding future climate conditions and the natural variability of climate in Wyoming, the overall goal of the WGFD is relatively simple and straightforward: continue to develop sound wildlife and habitat management policies and continue to employ sound wildlife and habitat conservation practices while evaluating a range of possibilities of future climate conditions and bringing climate into the planning and management processes as appropriate.
Projections of a warmer and drier climate in the western U.S. warrants the consideration of wildlife and habitat managers. Strategies that are practical across a range of possible future climate conditions will provide wildlife and habitat managers with the flexibility needed to adjust those strategies as appropriate and will not limit or inhibit future management options. Mitigating current threats to aquatic and terrestrial wildlife populations and habitat integrity, monitoring species and ecosystem health, and managing species populations, communities, and landscapes in accordance with what is known about natural disturbance regimes and ecosystem processes are good wildlife and habitat management strategies, as well as good climate change management strategies. Regardless of the accuracy of messages concerning climate change, it is important to maintain realistic and attainable management goals and objectives.

Scenario planning is a strategy that allows resource managers to evaluate current goals and objectives in light of climate change and to identify management actions that will address a range of issues facing aquatic and terrestrial wildlife populations.
Building scenarios involves the consideration of several likely directions and intensities of future climate change without requiring exact temperature and precipitation predictions. This type of planning acknowledges the uncertainty in climate projections and biotic response and provides resource managers a framework in which to better consider how various future climate conditions may impact the ecosystems, system components, and processes that they manage. Further, resource managers can evaluate how current goals may need to change and assess the future efficacy of current management strategies given a variety of climate scenarios. During a workshop on climate change organized by the WGFD in January 2010, participants were challenged to carry out a scenario planning exercise to evaluate the potential impacts of climate change on sagebrush ecosystems and the North Platte riverine ecosystem.

In addition to scenario planning, adaptive management techniques may help wildlife and habitat managers deal with the uncertainty surrounding future climate conditions.
Adaptive management involves the continual reevaluation through monitoring and improvement of management strategies as climate change plays out and causes sometimes predictable and sometimes unpredictable impacts on ecosystems and species communities. Managing for a historic range of variation and favoring the maintenance of native species populations and community structure may become increasingly costly and impractical in future climates. Both short-term and long-range management strategies will be necessary to deal with future climate variability. These strategies have usually guided by past experience and historical records. Given what is known about historical climate variation in the West and the future climate projections for this region, the coming decades may prove to be quite different than recent previous decades. Predictive models, flexibility, and adaptive management will be key to dealing with this

uncertainty, as will a policy-making and management environment that supports creativity and moderate risk-taking. The use of historical records and trends may no longer be sufficient for developing future management strategies.

Wildlife and habitat managers will likely pursue a combination of mitigation and adaptation measures as they employ strategies to maintain the health of aquatic and terrestrial flora and fauna and the integrity of the Wyoming landscapes that support these species.
Mitigation strategies involve actions that lessen the input of greenhouse gases into the atmosphere and are more likely to develop as state-level policy. Adaptation strategies, on the other hand, are not meant to resist inevitable changes or slow their occurrence, but are measures adopted to build the capacity of a species or ecosystem to deal with the impacts of climate change while maintaining stability and ultimately adapting and thriving under new conditions. An adaptation strategy may involve enhancing the quality, quantity, and connectivity of wildlife habitat so that wildlife populations are able to adjust their range according to physiological tolerances to changing climate conditions. Building and maintaining ecosystem health in order to accommodate change as opposed to resisting it is fast becoming the preferred method for wildlife management in the face of climate change.

Recommendations – General

Pursue financial, technical, and human resources to develop and implement a structure to coordinate the incorporation of climate change into WGFD activities at the agency level.
The WGFD will need a coordinated approach in order for climate change considerations to be effectively incorporated into WGFD planning and monitoring, and also to aid the timely development and implementation of projects and strategies addressing the impacts of changing climate conditions. This will require the WGFD to have increased authority, staff, and technical and financial resources.

A point person from within the department would serve as a contact for communication with federal resource management agencies and the public, and would also aid with the intra-agency dissemination of information regarding climate change and the coordination of all other climate change-related efforts.

Evaluate the potential impacts of climate change on Wyoming's key ecosystems, ecosystem components, ecosystem processes, WGFD management goals, strategies, and major challenges as an ongoing strategy.
One of the first steps to integrating climate change into planning, management, and monitoring efforts involves evaluating current goals and objectives and viewing current management challenges through a climate change lens. Understanding how climate change may impact key ecosystem components (i.e., species and habitat features) and processes that are essential to attaining management goals for SGCN, non-SGCN, and associated habitats is an important primary consideration and action that should be given serious attention by wildlife and habitat managers. Given the uncertainty about the exact changes of future temperature and precipitation, but with knowledge about the general trajectory that future climate may follow according to various climate models (i.e., warmer, drier, more variable), this challenge may be aided by the scenario building approach.

In 2010, WGFD organized a workshop to begin to evaluate the potential impacts of climate change on sagebrush and riverine ecosystems using a scenario building approach. Wildlife and habitat managers should expand on this effort and use existing knowledge about key terrestrial and aquatic ecosystems and wildlife to begin an informal scenario building process to gain increasing understanding about the influence of climate on wildlife and habitat management, and also how current goals, strategies, and challenges may be affected by changing climate. The impacts of several climate scenarios (e.g., current/historical, warmer with more seasonal precipitation, warmer with no change in seasonal precipitation, and warmer with a decrease in seasonal precipitation) on the specific habitat types outlined in the SWAP (e.g., sagebrush, riparian, etc.,), game species, SGCN, and ecosystem processes (e.g., periodic wildfire or grazing regimes) should be evaluated as an ongoing effort.

As wildlife and habitat managers begin to consider the potential impacts of climate change on the species and landscapes that they manage, it will be necessary to periodically evaluate the actual impacts of climate conditions on current management goals and strategies. The efficacy of some management techniques and the practicality/cost of some management goals may change with changing climate conditions. WGFD should take the appropriate steps to consider these impacts.

Identify and prioritize implementation actions that will benefit management targets by addressing a range of stressors given various future climate scenarios as an ongoing strategy.
After the potential impacts of several scenarios have been assessed and current management challenges considered in light of climate change, a range of no regret actions may be identified that address multiple issues and management challenges relating to both species and habitat. The desired outcome of the WGFD 2010 workshop on climate change was to develop a range of possible strategies to address the potential impacts of various climate scenarios on sagebrush and riverine ecosystems. Adaptive management techniques supported by internal policies that encourage creativity and moderate risk-taking may aid wildlife and habitat managers in developing and implementing strategies that safeguard these resources against multiple stressors.

Partner with other agencies and organizations, and support initiatives related to climate change and wildlife and habitat management as an ongoing strategy.
Engaging in a variety of partnerships is an effective means of cost-sharing, compensating for limited human and technical resources, and avoiding the duplication of effort. Statewide and regional interagency collaboration will facilitate information sharing, the assignment of appropriate roles to partner agencies, the request of appropriate data products from partner agencies, and the more efficient allocation of scarce resources for wildlife and landscape conservation. Additionally, partnerships may offer funding opportunities for climate-related research, mitigation, and adaptation projects. Coordinating efforts with federal, state, local, and non-profit partners should be an ongoing priority when dealing with climate issues.

WGFD should continue to participate in regional partnerships such as Landscape Conservation Cooperatives, continue to work with conservation organizations to achieve wildlife and habitat management goals, stay informed about state and local efforts related to climate change and support these efforts with technical or financial assistance when appropriate (e.g., WLCI, see section on Current Efforts), and identify sources of funding for climate-related research and projects.

Offer additional education opportunities for WGFD employees about climate change issues pertaining to wildlife and habitat management in Wyoming as an ongoing strategy.
The development of appropriate goals and the implementation of timely and successful strategies will require that agency employees are well-informed on how to integrate climate change into monitoring, planning, and management within the context of their current jobs. A point person for the dissemination of information may be beneficial for this purpose (see recommendation under Evaluating/Monitoring Success). Fostering an environment of increased awareness about climate and wildlife/landscape-related issues through individual and group education

opportunities is important. WGFD has organized climate change workshops in the past and should continue to organize workshops to discuss future climate projections and to specifically aid employees with the scenario building process, the enhancement of existing data-gathering programs to account for climate factors, and the development of adaptive management techniques.

Disseminate information to the public about climate change issues pertaining to wildlife and habitat management in Wyoming.
Hunters, anglers, and wildlife viewers are important stakeholder groups within the state. The dissemination of information to the public regarding the observed and future potential impacts of climate change on wildlife and habitat in Wyoming will be necessary. The use of existing forms of media provides an opportunity to convey climate-related issues to Wyomingites and to gain public feedback on proposed mitigation and adaptation measures. WGFD should consider using Wyoming Wildlife magazine and existing newsletters as forums for discussing appropriate and timely climate-related issues. Additionally, WGFD should consider developing future climate change workshops for public attendance and participation, and relate the topic of climate change to current and accepted wildlife management issues.

Work with regional organizations to evaluate existing laws and regulations and make recommendations in light of climate change as a long-term consideration.
Existing regulations and policies may need to be reexamined and/or modified to safeguard wildlife and habitat and to support reasonable conservation expectations as changes in climate occur. Dealing with certain laws will be a challenge if species become increasingly threatened by climate change and variability. Much like the development of strategies, policies should be flexible and should be revisited or revised more often to assess the need for changes and to avoid the use of scarce resources on hopeless causes. Timely recommendations on policy adjustments to either mitigate the effects of climate change or aid climate change adaptation should be welcomed and given due consideration. WGFD should work with regional organizations such as the Western Governors' Association and the Association of Fish and Wildlife Agencies to identify and recommend needed statutory and regulatory changes at the state and federal levels.

Recommendations – Species Management

Wildlife managers should continue to focus on good wildlife management techniques, including reducing non-climate stressors and promoting biological and genetic diversity.
Continuing to enhance efforts to minimize the impacts of non-climate stressors and continuing to manage for species and genetic diversity will help safeguard individual species populations and species communities from any current or future threats (e.g., development pressures, natural disturbances, climate change) by increasing species' ability to adapt to environmental changes. WGFD should continue management practices that balance the abundance of wildlife populations with the carrying capacity of the land (e.g., big game management using harvest quotas), while also focusing on biodiversity (e.g., SGCN), and use existing knowledge about non-climate stressors affecting aquatic and terrestrial species to continue to enhance strategies to address these wildlife stressors (e.g., Aquatic Invasive Species program and initiatives to control invasive terrestrial flora).

Wildlife managers should build an understanding of past responses to climate change and climate as a driver of species behavior, range, and distribution.
Climate change and variability impacts species individually and may result in previously unforeseen vulnerabilities on Wyoming's wildlife. Climate change may have significant ecological and economic effects, including impacting hunter and angler recruitment and retention, causing the decline of SGCN, and

leading to the establishment and continued proliferation of populations of nonnative species in the state.

Understanding how species have responded to stresses and disturbances in the past may provide wildlife managers with important insight about how species may respond in the future to climate change and stressors that are expected to be compounded by climate change. The use of existing research, literature, and experience, as well as utilizing historical data sets compiled by the USA National Phenology Network (http://www.usanpn.org/), may aid wildlife managers in building an understanding of climate as a driver of species behavior, range, and distribution. Although uncertainty exists, the use of historical climate data, available through the Wyoming State Climate Office, in conjunction with long-term data sets documenting species behavior or characteristics may contribute to this understanding. Wildlife and habitat managers should identify research and information needs and develop strategies to bridge knowledge gaps regarding the relationship of individual species and climate.

Assess the vulnerability of SGCN to climate change and evaluate the impacts of climate on select species.

Conducting species vulnerability assessments to determine which species are at high, medium, and low risk of being impacted by climate change should be considered before the next revision of the SWAP. A comprehensive climate change vulnerability assessment that is external to the Native Species Status matrix but could be incorporated into it will help wildlife managers evaluate the relative sensitivity, level of exposure, and adaptive capacity of the species that they manage. Managers may also be able to identify species with certain patterns of habitat use (e.g., sagebrush obligate species) and specific taxa that are at highest risk, which may aid future mitigation or adaptation efforts. WGFD should consider using the Climate Change Vulnerability Index (CCVI) developed by NatureServe (see section on Current Efforts) as a means to evaluate the vulnerability of Wyoming's SGCN. Furthermore, WGFD should determine who needs to be involved in the vulnerability assessment process for the results to be accepted as credible. An interim publication may be considered to distribute the results of the CCVI before the next revision of the SWAP.

WGFD should take necessary steps to evaluate the observable and realized effects of climate conditions and climate-related disturbances on wildlife. WGFD should consider SGCN as well as recreational and economically important species. However, the department should begin by using the CCVI to select a few SGCN that are ranked as having high vulnerability to climate change, and evaluate the impacts of climate conditions on these species at regular intervals before the next revision of the SWAP. The evaluation of all other species may be a long-term consideration as resources allow, or taken up on a species-by-species basis in the case of a status change that warrants additional attention. Existing wildlife monitoring programs that may already be tracking changes in species health and behavior should be identified and utilized (e.g., USA National Phenology Network), and WGFD should continue to execute or participate in wildlife surveys to specifically monitor population dynamics.

Evaluate the feasibility of developing approaches to model future species distribution based on multiple drivers, including climate change. Build databases and produce maps depicting future species distribution including climate as a driver as a long-term consideration.

The SWAP includes current distribution maps for SGCN. Consideration should be given to developing maps of the potential future distribution of both SGCN and non-SGCN species based on key drivers of distribution, including climate factors. Evaluating the feasibility of using current species distribution maps to model the future distribution of species is a first step to understanding the potential impacts of climate change on individual species. Additional baseline information may be needed to produce maps that accurately depict future species distribution contingent upon multiple drivers, and knowledge gaps should be filled through continued research efforts or by obtaining data from the appropriate sources. Wildlife managers should identify the key drivers of SGCN and non-SGCN distribution and assess the feasibility and the quality and completeness of data for mapping the future distribution of SGCN and non-SGCN as a goal before the next revision of the SWAP. Producing maps for species with sufficient data and clear drivers of distribution may be a long-term consideration.

Downscaled climate data and finer-scale climate models may be necessary to make appropriate species management decisions in the future, and the availability of this data should be evaluated.
Modeling future species distributions and developing a clearer understanding about future climate scenarios across Wyoming will require more precise information about temperature and precipitation predictions. Through regional partnerships involving scientist and organization that are working on downscaling climate date to a relevant level for wildlife managers, asses the availability and quality of downscaled climate models for Wyoming and identify information gaps to guide development of finer scale models.

Assess the impacts of climate on disease dynamics. Incorporate this information in ongoing disease monitoring, and enhance disease distribution mapping, both current and projected
WGFD currently tracks and monitors diseases that are specific to certain species or populations, and is updating a wildlife disease manual that describes diseases that affect species in Wyoming. Additional research on the influence of climate factors on disease incidence and/or prevalence would complement existing knowledge and may benefit wildlife managers in the future by allowing them to establish a network of early detection sites where future cases of disease are likely to emerge given climate conditions and other factors. WGFD should continue to support research efforts to establish links between climate factors and the ecology of both aquatic and terrestrial wildlife diseases, including pathogens, vectors, and hosts. WGFD should also work with other agencies to understand the links between climate and mountain pine beetle, as the drastic alteration of Wyoming's conifer forests or precautionary closure of public lands will have significant implications for future wildlife and habitat management. WGFD should enhance wildlife disease monitoring efforts to describe the current distribution of diseases and predict potential future distribution or locations conducive to outbreaks based on known drivers as a long-term consideration.

Recommendations – Habitat Management

Habitat managers should continue to focus on sound conservation, restoration, and management practices as outlined in the WGFD Strategic Habitat Plan, which will help maintain the integrity of ecosystem structure and function in the face of many ecosystem stressors, including climate change.
Continuing to implement good aquatic and terrestrial habitat management practices will help maintain regular hydrological flows by regulating peak flows, increasing terrestrial water storage, and controlling late-season flows. WGFD should utilize existing data systems and tools to identify natural watershed storage features to aid in land management decision-making and continue to develop and execute wetland and riparian restoration projects, which will increase the distribution and function of the quantity of stored water.

Ecosystem restoration, or on a smaller scale habitat restoration, may be considered both a mitigation and adaptation strategy as intact systems store more CO_2 and positively feed into species health and biodiversity. Habitat managers may want to consider emphasizing ecosystem function and diversity over the maintenance of specific communities of species as climate change may cause managing for historic conditions to become increasingly costly, challenging, and impractical. WGFD should continue to work with private landowners, government agencies, and conservation organizations to manage landscapes to meet the needs of wildlife and to address access issues, and continue to support conservation programs, such as NRCS habitat extension programs, that aid landowners with the restoration and long-term protection of natural ecosystems.

Promote connectivity as outlined in the Strategic Habitat Plan as an ongoing strategy, and undertake additional mapping efforts that depict critical areas of wildlife movement, transition, and refuge as an ongoing strategy.
Increasing the overall amount and connectivity of habitat, including migration corridors, transitional areas, and refugia, is a strategy that will build ecosystem health and species resilience to a variety of stressors. Porous landscapes, or those that are easily traversed by fish and terrestrial wildlife, will allow some species to adjust to changing environmental conditions through population movement. Riparian areas may become particularly important as wildlife movement corridors and may require special focus. WGFD should continue to work with private landowners, government agencies, and conservation organizations to restore and maintain habitat connectivity and to connect core conservation areas by encouraging the development of solutions to help wildlife bypass obstructions, such as wildlife-friendly fencing and highway underpasses for terrestrial species and channels for aquatic species to move around waterway obstructions. WGFD should also continue to build the fish passage database to catalogue obstructions on Wyoming waters.

WGFD should use existing knowledge to map and prioritize wildlife corridors, transitional grounds, and refugia as an ongoing strategy to aid future management and land conservation efforts under changing climate conditions

Consideration should be given to conducting habitat vulnerability assessments as an ongoing strategy.
As with species management, the consideration of climate factors in habitat management may require additional research and data gathering to fill knowledge gaps. The identification of terrestrial and aquatic areas that may become priority areas for management in the future will require the evaluation of the potential impacts of climate factors and other stressors on habitat types and focal areas. Conducting vulnerability assessments on habitat may be equally as important as species vulnerability assessments. WGFD should assess and rank the vulnerability of focal areas to threats from energy development (including renewable energy development and carbon sequestration projects), rural subdivision, climate change, invasive species, and the disruption of natural disturbance regimes. Consideration should also be given to evaluating the potential impacts of climate change on what are currently defined as “crucial areas” and “enhancement areas” in the Strategic Habitat Plan.

WGFD should also begin to evaluate the observable and realized impacts of climate and climate-related disturbances on habitat using the 11 terrestrial habitat types and 6 aquatic basins that are described in the SWAP as units to compile and assess this information. Existing monitoring programs that are already tracking climate-driven landscape/hydrologic changes (e.g., USGS Streamgage Program) should be identified and utilized. WGFD should continue current habitat monitoring programs with consideration of the addition of a climate component to begin tracking the impacts of climate-related factors on management targets (e.g., monitoring water temperature changes in trout habitat). WGFD may consider doing a thorough analysis of the impacts of climate conditions on select habitat types as a long-term consideration.

Evaluating/monitoring Success

After wildlife and habitat managers have developed an idea of how climate change may affect the species and landscapes that they manage and have ranked the relative vulnerability of species and/or habitats, incorporating the predicted impacts into species and land management plans will be the next step. Modifying existing protocols or developing new protocols and enhancing existing programs for monitoring the impacts of climate change on wildlife and ecosystems requires wildlife and habitat managers to determine what to monitor and to identify indicators of climate-driven change or early warning signs of climate-related stress.

WGFD should identify species and climate-driven behaviors that may provide an early indication of climate-related environmental change. For instance, species that are particularly susceptible to hydrological changes or species that have observable phenology such as migration and breeding patterns may provide wildlife managers with indicators of ecosystem change resulting from changing climate conditions from which they can begin to anticipate other changes or start to re-evaluate management goals and strategies. Similarly, WGFD should identify and monitor climate-driven landscape changes that may impact the efficacy of current management strategies and provide insight on potential future conditions.

Develop standard monitoring protocols.
In order to effectively monitor the impacts of current and future climate conditions on wildlife and landscapes, the WGFD may need to modify existing protocols or develop new protocols to capture specific climate-related information that will be valuable for the future development of mitigation and/or adaptation strategies for wildlife and habitat. Standardizing these monitoring protocols across the WGFD should be an ongoing effort, and the department may want to consider investigating methods and assessment tools that have been developed and successfully implemented by other states or regular partner agencies/organizations. Factors that should be assessed in terms of climate trends and local impacts include habitat, physiology, phenology, and species interactions.

Establish a reasonable planning timeline as part of a long-term strategy.
It is not practical to carry out all strategies and recommendations at once. WGFD will need to determine which actions are feasible now and which should be done in the future—and at what point in the future. A reasonable planning timeline will be key to the successful evaluation of the impacts of climate on species, ecosystems, and processes, as well as the implementation of timely mitigation and adaptation strategies. WGFD should develop a planning timeline for developing and implementing new climate monitoring protocols and programs for the most sensitive species and the most vulnerable landscapes.

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Literature Cited

ARCHER, S. R. AND K. PREDICK. 2008. Climate change and ecosystems of the Southwestern United States. Rangelands, 23–28.

BACKLUND, P., A. JANETOS, D. S. SCHIMEL, J. HATFIELD, M. G. RYAN, S. R. ARCHER, AND D. LETTENMAIER, 2008. Executive summary. *In*: The effects of climate change on agriculture, land resources, water resources, and biodiversity in the United States. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Washington, DC.

BARNETT, T., R. MALONE, W. PENNELL, D. STAMMER, B. SEMTNER AND W. WASHINGTON. 2004. The effects of climate change on water resources in the West: introduction and Overview. Climatic Change 62: 1–11.

BEEVER, E. A., P. F. BRUSSARD AND J. BERGER. 2003. Patterns of apparent extirpation among isolated populations of pikas (*Ochotona princeps*) in the Great Basin. J. Mammal. 84:37–54.

BOISVENUE, C. AND S. W. RUNNING. 2006. Impacts of climate change on natural forest productivity – evidence since the middle of the 20th century. Global Change Biology 12: 862–882.

BRADLEY, B. 2010. Assessing ecosystem threats from global and regional change: hierarchical modeling of risk to sagebrush ecosystems from climate change, land use and invasive species in Nevada, USA. Ecography 33(1):198–208.

BUREAU OF LAND MANAGEMENT. Undated. Understanding the problem of climate change and western ecosystems: considerations and tools for ecoregional Assessment. http://www.blm.gov/pgdata/etc/medialib/blm/wy/programs/science.Par.23352.File.dat/ClimateChange-EcoregionalAssessment.pdf.

CAYAN, D. R., S. A. KAMMERDIENER, M. D. DETTINGER, J. M. CAPRIO AND D. H. PETERSON. 2001. Changes in the onset of spring in the western United States. Bull. Am. Meteorol. Soc. 82: 399–415.

CHRISTENSEN, J. H., B. HEWITSON, A. BUSUIOC, ET AL. 2007: Regional climate Projections. *In*: Climate change 2007: the physical science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller (eds.)). Cambridge University Press, Cambridge, United Kingdom and New York, NY.

COPELAND, H. E., S. A. TESSMAN., E. H. GIRVETZ, L. ROBERTS, C. ENQUIST, A. ORABONA, S. PATLA AND J. KIESECKER. 2010. A geospatial assessment on the distribution, condition, and vulnerability of Wyoming's wetlands. Ecological Indicators 10: 869–879.

DUNHAM, J. B., M. K. YOUNG, R. E. GRESSWELL AND B. E. RIEMAN. 2003. Effects of fire on fish populations: landscape perspectives on persistence of native fishes and nonnative fish invasions. Forest Ecology and Management 178:183–196.

FICKE, A. D., C. A. MYRICK AND L. J. HANSEN. 2007. Potential impacts of global climate change on freshwater fisheries. Rev Fish Biol Fisheries 17:581–613.

FIELD, C. B., L. D. MORTSCH, M. BRKLACICH, D. L. FORBES, P. KOVACS, J. A. PATZ, S. W. RUNNING AND M. J. SCOTT. 2007. North America. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden and C. E. Hanson, eds.) Cambridge University Press, Cambridge, UK, 617–652.

GRAY, S.T . AND C. ANDERSEN. 2009. Assessing the future of Wyoming's water resources: adding climate change to the Equation. William D. Ruckelshaus Institute of Environment and Natural Resources. University of Wyoming, Laramie, WY.

GRAY, S. T., J. L. BETANCOURT, S.T. JACKSON AND R.G. EDDY. 2006. Role of multidecadal climate variability in a range extension of pinyon pine. Ecology Volume 87 (5):1124–1130.

GROISMAN, P. Y., R. W. KNIGHT, T. R. KARL, D. R. EASTERLING, B. SUN AND J. H. LAWRIMORE. 2004. Contemporary changes of the hydrological cycle over the contiguous United States: trends derived from in situ observations. J. Hydrometeorol. 5:64–85.

HARRINGTON, R., I. WOIWOD AND T. SPARKS. 1999. Climate change and trophic interactions. Trends Ecol. Evol. 14:146–150.

HARVELL, C. D., C. E. MITCHELL, J. R. WARD, S. ALTIZER, A. P. DOBSON, R. S. OSTFELD AND M. D. SAMUEL. 2002. Climate warming and disease risks for terrestrial and marine biota. Science 296:2158–2162.

HAYS, P. "Water and Climate Change." Microsoft® Office PowerPoint® presentation. Cheyenne, WY. 16 June 2008. http://gf.state.wy.us/downloads/pdf/climatechange workshop/Water% 20and%20 Climate%20Change.pdf.

HICKE, J. A., J. A. LOGAN, J. POWELL AND D. S. OJIMA. 2006. Changing temperatures influence suitability for modeled mountain pine beetle (Dendroctonus ponderosae) outbreaks in the western United States. Journal of Geophysical Research 111:1–12.

HOERLING, M. AND J. EISCHEID. 2007. Past peak water in the Southwest. Southwest Hydrology 6(1):18–19.

INOUYE, D. W., B. BARR, K. B. ARMITAGE AND B. D. INOUYE. 2000. Climate change is affecting altitudinal migrants and hibernating species. Proc. Natl. Acad. Sci. USA 97:1630–1633.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE. 2007. Climate change 2007: synthesis report. IPCC Plenary XXVII (Valencia, Spain, 12–17 November 2007).

JACKSON, S. T., J. L. BETANCOURT, R. K. BOOTH AND S. T. GRAY. 2009. Ecology and the ratchet of events: climate variability, niche dimensions, and species distributions. PNAS 106(suppl. 2):19685–19692.

JESCHKE, J. M. AND D. L. STRAYER. 2008. Usefulness of bioclimatic models for studying climate change and invasive species. Annals of the New York Academy of Sciences 1134:1–24.

JOYCE, L. A., D. OJIMA, G. SEIELSTAD, R. HARRISS AND J. LACKETT. 2000. Potential consequences of climate variability and change for the Great Plains. *In*: Climate change impacts on the United States: the potential consequences of climate variability and change. U.S. Global Change Research Program, Washington D.C., 2000.

JOYCE, L., R. HAYNES, R. WHITE AND R. J. BARBOUR, TECH CORDS. 2007. Bringing climate change into natural resource management: proceedings. Gen. Tech. Rep. PNW-GTR-706. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

KNOWLES, N., M. D. DETTINGER AND D. R. CAYAN. 2006. Trends in snowfall versus rainfall for the western United States, 1949-2004. J. Climate 19:4545–4559.

KOOPMAN, M. “Potential Responses of Wildlife to Climate Change.” Microsoft® Office PowerPoint® presentation. Cheyenne, WY. 16 June 2008. http://gf.state.wy.us/downloads/pdf/climatechangeworkshop/Potential%20Response%20of%20Wildlife%20to%20Climate%20Change.pdf.

LOGAN, J. A., J. REGNIERE AND J. A. POWELL. 2003. Assessing the impact of global warming on forest pest dynamics. Frontiers in Ecology and the Environment 1(3):130–137.

LUCHT, W., I. C. PRENTICE, R. B. MYNENI, S. SITCH, P. FRIEDLINGSTEIN, W. CRAMER, P. BOUSQUET, W. BUERMANN AND B. SMITH. 2002. Climate control of the high-latitude vegetation greening trend and Pinatubo effect. Science 296:1687–1689.

LYFORD, M. E., S. T. JACKSON, J. L. BETANCOURT AND S. T. GRAY. 2003. Influence of landscape structure and climate variability on a late Holocene plant migration. Ecological Monographs 73:567–583.

MANCI, K. M. AND K. A. SCHNELLER-MCDONALD. 1989. Riparian Ecosystem Creation and Restoration: A Literature Summary. US Fish and Wildlife Service Biological Report. http://www.npwrc.usgs.gov/resource/habitat/ripareco/. (Accessed 13 July 2010.)

MANLEY, P. 2008. Biodiversity and Climate Change. Climate Change Resource Center. http://www.fs.fed.us/ccrc/topics/biodiversity.shtml.

MCWETHY, D. B., S. T. GRAY, P. E. HIGUERA, J. S. LITTELL, G. S. PEDERSON, A. J. RAY AND C. WHITLOCK. 2010. Climate and ecosystem change in the U.S. Rocky Mountains and Upper Columbia Basin: historical and future perspectives for natural resource management (draft). Report for the National Park Service, Great Northern Landscape Conservation Cooperative and the Greater Yellowstone Coordinating Committee.

MIDGLEY, G. F., L. HANNAH, D. MILLAR, M. C. RUTHERFORD AND L. W. POWRIE. 2002. Assessing the vulnerability of species richness to anthropogenic climate change in a biodiversity hotspot. Global Ecology & Biogeography 11: 445–451.

MOTE, P., A. F. HAMLET, M. P. CLARK AND D .P. LETTENMAIER. 2005. Declining mountain snowpack in western North America. Bull. Amer. Meteor. Soc. 86:39–49.

MYNENI, R. B., J. DONG, C. J. TUCKER, P. E. KAUFMANN, J. KAUPPI, L. LISKI, J. ZHOU, V. ALEXEYEV, AND M. K. HUGHES. 2001. A large carbon sink in the woody biomass of northern forests. Proc. Nat. Acad. Sci. 98:14784–14789.

NICHOLOFF, S. H., COMPILER. 2003. Wyoming bird conservation plan, Version 2.0. Wyoming Partners In Fligh Wyoming Game and Fish Department, Lander, WY.

NATIONAL OCEAN AND ATMOSPHERIC ADMINISTRATION. 2008. Perspective on abrupt climate Change. National Climate Data Center. Accessed 15 June 2010. http://www.ncdc.noaa.gov/paleo/abrupt/story1.html.

PARMESAN, C. AND H. GALBRAITH. 2004. Observed Ecological Impacts of Climate Change in North America. Arlington, VA: Pew Center on Global Climate Change.

PARMESAN, C. AND G. YOHE. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421:37–42.

PARMESAN, C. 2006. Ecological and evolutionary responses to recent climate change. Annual Review of Ecology, Evolution, and Systematics 37:637–669.

PEW CENTER ON GLOBAL CLIMATE CHANGE. Undated. Wyoming Carbon Capture and Storage Legislation. Pew Center on Global Climate Change. http://www.pewclimate.org/node/6428. (Accessed 13 July 2010.)

PITELKA, L. F. AND THE PLANT MIGRATION WORKING GROUP. Plant migration and climate change. 1997. Am. Sci. 85:464–473.

PULWARTY, R., K. JACOBS AND R. DOLE. 2005. The hardest working river: drought and critical water problems in the Colorado River Basin. Drought and Water Crisis – Science, Technology and Management Issues. D.A. Wilhite, ed. CRC Press: Boca Raton, FL, 249–286.

RAHEL, F. J., C. J. KELEHER AND J. L. ANDERSON. 1996. Potential habitat loss and population fragmentation for cold water fish in the North Platte River drainage of the Rocky Mountains: response to climate warming. Limnol Oceanogr 41(5):1116–1123.

REGONDA, S. K., B. RAJAGOPALAN, M. CLARK AND J. PITLICK. 2005. Season cycle shifts in hydroclimatology over the western United States. Journal of Climate 18:372–384.

RIEMAN, B. AND J. CLAYTON. 1997. Wildfire and native fish: issues of forest health and conservation of sensitive species. Fisheries 22(11):6–15.

ROMME, W. H., J. CLEMENT, J. HICKE, D. KULAKOWSKI, L. H. MACDONALD, T. L. SCHOENNAGEL AND T. T. VEBLEN. 2006. Recent forest insect outbreaks and fire risk in Colorado forests: a brief synthesis of relevant Research. Colorado Forest Restoration Institute.

ROOT, T. L. AND S. H. SCHNEIDER. 2002. Climate change: overview and implications for Wildlife. *In*: wildlife responses to climate change: North American case Studies. S. H. Schneider and T .L. Root, eds. (Island Press, Washington DC.) 1–56.

ROOT, T. L., J. T. PRICE, K. R. HALL, S. H. SCHNEIDER, C. ROSENZWEIG AND J. A. POUNDS. 2003. Fingerprints of global warming on wild animals and plants. Nature 421:57–60.

ROSENZWEIG, C., D. KAROLY, M. VICARELLI, ET AL. 2008. Attributing physical and biological impacts to anthropogenic climate change. Nature 453:353–357.

RUGGIERO, L., K. MCKELVY, J. SQUIRES AND W. BLOCK. 2008. Wildlife and Climate Change. Climate Change Resource Center. http://www.fs.fed.us/ccrc/topics/wildlife. shtml.

SCHMITZ, O. J., E. POST, C. E. BURNS AND K. M. JOHNSTON. 2003. Ecosystem responses to global climate change: moving beyond color mapping. BioScience 53(12):1199–1205.

SCHNEIDER, S. H. AND T. L. ROOT. 1998. Climate change. *In*: Status and Trends of the Nation's Biological Resources. M. J. Mac, P. A. Opler, C. E. Puckett Haecker, and P. D. Doran eds. Vol. 1. U.S. Department of the Interior, U.S. Geological Survey, Reston, VA. pp. 89–116.

SCIENCEDAILY. 2008. Impact of beetle kill on Rocky Mountain weather, air quality. ScienceDaily. http://www.sciencedaily.com/releases/2008/09/080924111147.htm. Materials provided by National Center for Atmospheric Research/University Corporation for Atmospheric Research.

SEAGER, R., M. TING, I. HELD, Y. KUSHNIR, ET AL. 2007. Model projections of an imminent transition to a more arid climate in Southwestern North America. Science 316(5828):1181–1184.

SPIGEL, K. M. AND P. R. ROBICHAUD. 2007. First-year post-fire erosion rates in Bitterroot National Forest, Montana. Hydrological Processes 21:998–1005.

STEFAN, H. G., X. FANG AND J. G. EATON. 2001. Simulated fish habitat changes in North American lakes in response to projected climate warming. Trans. Amer. Fish. Soc. 130:459–477.

STEWART, I. T., D. R. CAYAN AND M. D. DETTINGER. 2005. Changes toward earlier streamflow timing across western North America. Journal of Climate 18:1136–1155.

STONEFELT, M. D., T. A. FONTAINE AND R. H.

HOTCHKISS. 2000. Impacts of climate change on water yield in the Upper Wind River Basin. J. Amer. Water Resour. Assoc. 36:321–336.

THE NATIONAL ACADEMIES. 2009. ecological impacts of climate change. The National Academy of Sciences. http://dels-old.nas.edu/dels/rpt_briefs/ecological_impacts.pdf.

U.S. CLIMATE CHANGE SCIENCE PROGRAM. Undated. Abrupt climate change: summary and Findings. U.S. Climate Change Science Program Synthesis and Assessment Report 3.4.

U.S. FISH AND WILDLIFE SERVICE. 2009. Rising to the challenge: strategic plan for responding to accelerating climate Change (revised draft). U.S. Fish and Wildlife Service.

VISSER, M. E. AND C. BOTH. 2005. Shifts in phenology due to global climate change: the need for a yardstick. Proc. R. Soc. B 272:2561–2569.

VISSER, M. E., C. BOTH, AND M. M. LAMBRECHTS. 2004. Global climate change leads to mistimed avian reproduction. Adv. Ecol. Res. 35:89–110.

WALTHER, G. R., E. POST, P. CONVERY, A. MENZEL, C. PARMESAN, T. J. C. BEEBEE, J. M. FROMENTIN, O. HOEGH-GULDBERG AND F. BAIRLEIN. 2002. Ecological responses to recent climate change. Nature 416:389–395.

WATER RESOURCES DATA SYSTEM. Undated. Climate: Summary from the Western Regional Climate Center. Accessed June 2010. http://www.wrds.uwyo.edu/sco/climate/wyoclimate.html.

WESTERLING, A. L., H. G. HIDALGO, D. R. CAYAN AND T. W. SWETNAM. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. Science 313:940–943.

WESTERN GOVERNORS' ASSOCIATION. 2008. Climate change working group. WGA Wildlife Corridors Initiative (23 June 2008 draft).

WIENS, J. A. AND D. BACHELET. 2009. Matching the multiple scales of conservation with the multiple scales of climate change. Conservation Biology 24(1):51–62.

WILCOX, B. P. 2010. Transformative ecosystem change and ecohydrology: ushering in a new era for watershed management. Ecohydrology 3:126–130.

Additional Resources

Assessments and Publications

Assessing the Future of Wyoming's Water Resources: Adding Climate Change to the Equation. An assessment conducted by the Ruckelshaus Institute of Environment and Natural Resources at the University of Wyoming, 2009. Available online at http://www.uwyo.edu/enr/.

Beyond Seasons' End: A Path Forward for Fish and Wildlife in the Era of Climate Change. A collaboration of Ducks Unlimited, Trout Unlimited, BASS/ESPN Outdoors, Izaak Walton League of America, Association of Fish & Wildlife Agencies, Coastal Conservation Association, American Sportfishing Association, Pheasants Forever, and Boone and Crockett Club. Published by the Bipartisan Policy Center, 2009.

Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. By Patty Glick and Bruce A. Stein. Published by the National Wildlife Federation, 2010 (draft).

The State of the Birds: 2010 Report on Climate Change. An assessment conducted by the North American Bird Conservation Initiative, American Bird Conservancy, Association of Fish & Wildlife Agencies, Cornell Lab of Ornithology, Klamath Bird Observatory, National Audubon Society, National Fish and Wildlife Foundation, The Nature Conservancy, U.S. Fish and Wildlife Service, U.S. Forest Service, and U.S. Geological Survey.

Voluntary Guidance for States to Incorporate Climate Change into State Wildlife Action Plans & Other Management Plans. A collaboration of the Association of Fish & Wildlife Agencies and Teaming with Wildlife, 2009.

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National Fish Habitat Action Plan
http://fishhabitat.org/

Western Native Trout Initiative
http://westernnativetrout.org/

Desert Fish Habitat Partnership
http://www.nature.nps.gov/water/DFH_partnership.cfm

Great Plains Fish Habitat Partnership
http://www.prairiefish.org/

NatureServe
Climate Change Vulnerability Index
http://www.natureserve.org/prodServices/climatechange/ccvi.jsp

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World Wildlife Fund
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http://www.worldwildlife.org/what/wherewework/ngp/index.html

Wyoming Game and Fish Department Climate Change Workshop
http://gfi.state.wy.us/ClimateChangeWS/index.asp

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